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MODELING AND SIMULATION, TESTING AND VALIDATION



Michigan Chapter
NDIA
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UTILIZATION OF FAST RUNNING MODELS IN BURIED BLAST SIMULATIONS OF GROUND VEHICLES FOR SIGNIFICANT COMPUTATIONAL EFFICIENCY

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- Objectives
- Methods
 - Fast Running Models
 - Blast Event Simulation sysTem Methodology and Validation
- Case Study: Notional V-hull Structure
- Future Applications and Development

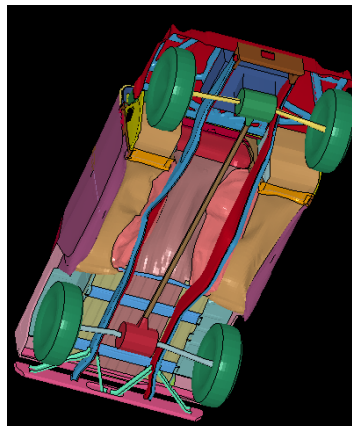
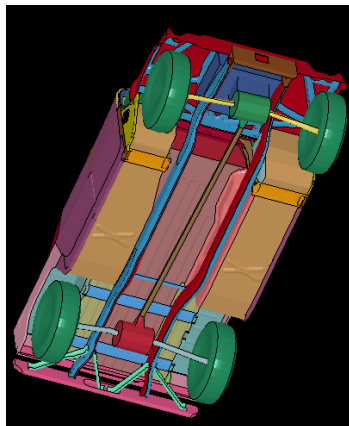
Objectives

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- Survivability assessment requires thorough and systematic exploration of threat effects
- Current computational approaches require significant wall-clock time
- Fast Running Models (FRMs) are paired with the Blast Event Simulation sysTem (BEST) to accelerate analysis

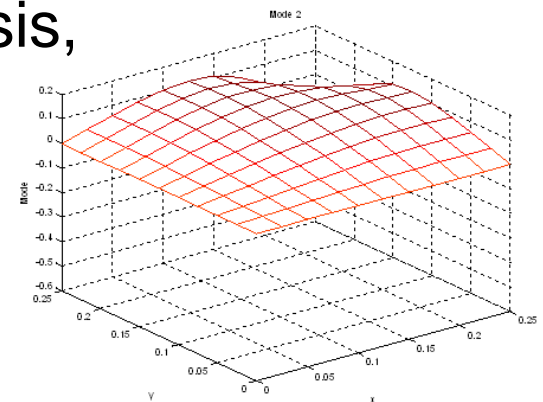
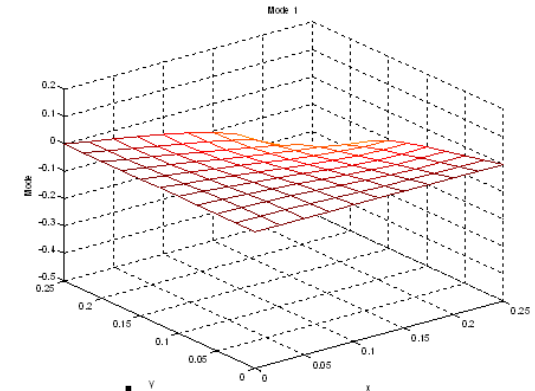


- FRMs comprise a reduced-order modeling approach that captures relevant physics governing relationships between input parameters and output effects
- Scenario parameters are input and time-series effects are output, much like complex multi-physics computational analysis
- Results are computed in seconds
- FRMs are a fusion of Principal Component Analysis (PCA) and Kriging

Principal Component Analysis



- Reduce dimensionality of data set
- Distill blast loading histories into 'modal' information
- No linear limitations, PCA isolates fundamental characteristics that can be used as an expansion basis
- PCA used for nonlinear structural analysis, image processing, shock analysis, automotive crash analysis, molecular dynamics and more



Principal Component Analysis



- Decompose response matrix X:

$$X = \begin{bmatrix} x_1(t_1) & \dots & x_1(t_k) \\ \vdots & \ddots & \vdots \\ x_J(t_1) & \dots & x_J(t_k) \end{bmatrix}$$



$$X = USV^T$$



$$X = [\Phi \quad \Phi_\tau] \begin{bmatrix} D & 0 \\ 0 & Z \end{bmatrix} \begin{bmatrix} \eta \\ \eta_\tau \end{bmatrix}$$

$$[U]$$

Each column is a “mode”

$$[\cancel{W}]$$

Only diagonal terms
energy in each “mode”

$$[\cancel{V}]^T$$

Modal participation
terms at each time
step



- Time-dependent, reduced-order model:

$$[X(\gamma)] = [U(\gamma)][W(\gamma)][V(\gamma)]^T$$

- Matrices generated by metamodels (Kriging):

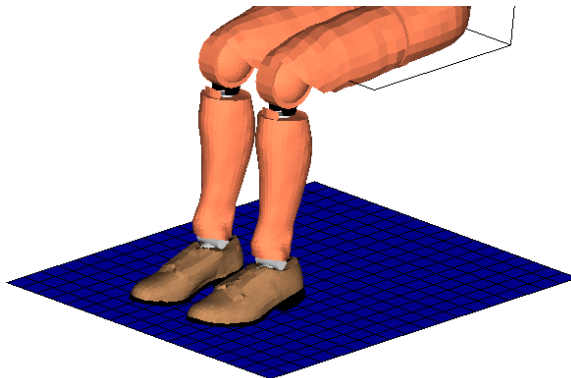
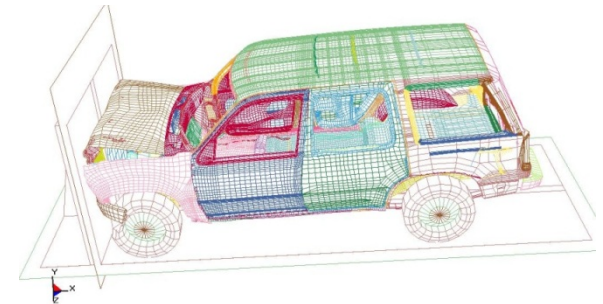
$$[U(\gamma)], [W(\gamma)], [V(\gamma)]^T$$

- Analyses are performed **at a limited number of training points**
- The values for [U], [W], [V] at the training points are used for developing the metamodels

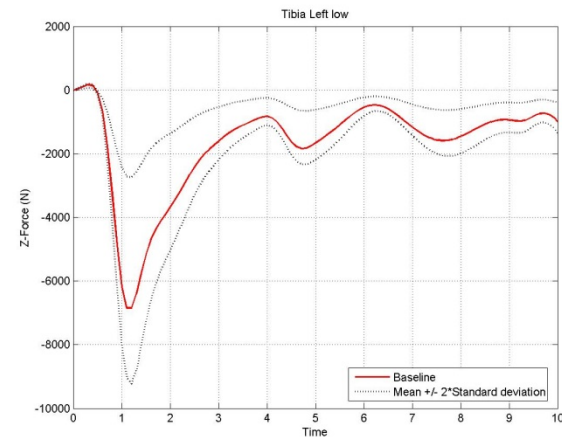
Previous Applications



- SAE-2005-01-2373 surface ship shock analysis
- SAE-2007-01-1744 automotive crash analysis
- SAE-2006-01-0762 uncertainty analysis for occupant safety under blast loads



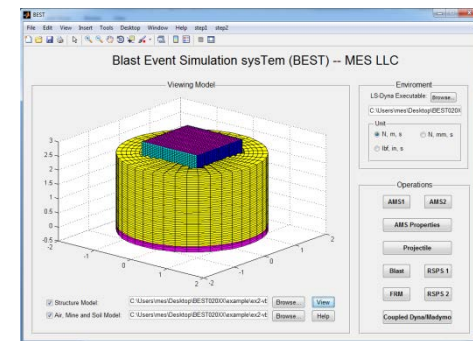
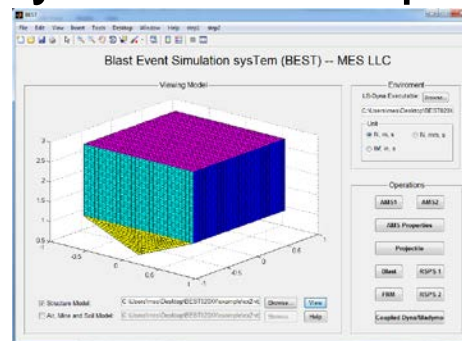
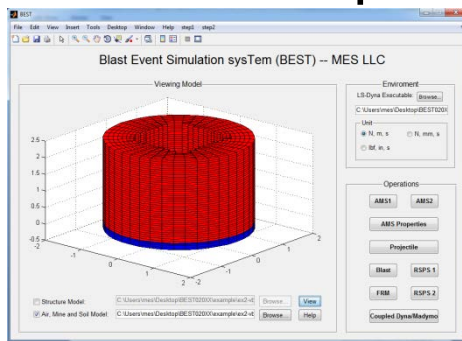
Time = 0.000000



Blast Event Simulation sysTem

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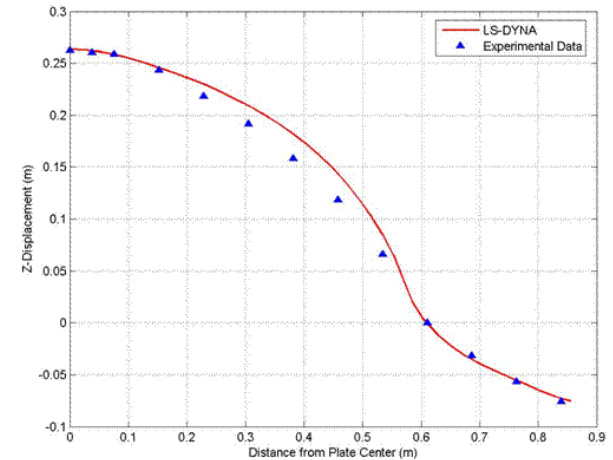
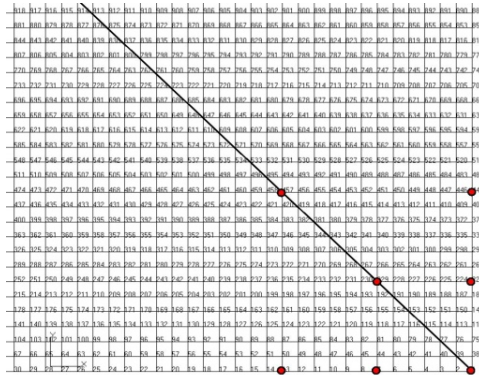
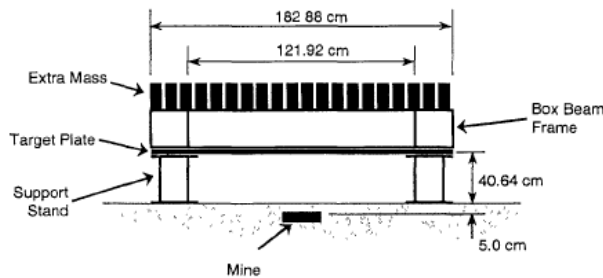
- Series of nested panels with buttons, input boxes, and drop down menus
- Organizes and automates mesh generation and simplifies simulation and post-processing
- Capable of defining and launching simulations and creating post-processing files through command line prompts and a suite of Fortran executables
- The FRM capability was developed within BEST



Previous Validation

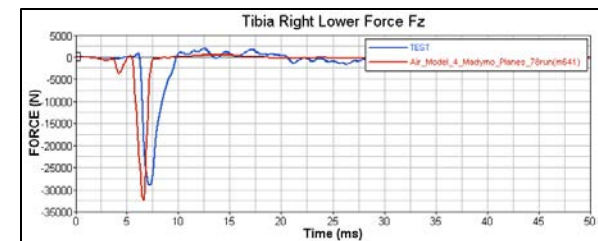
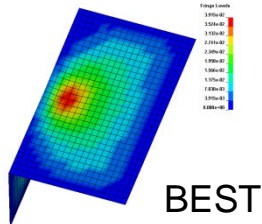
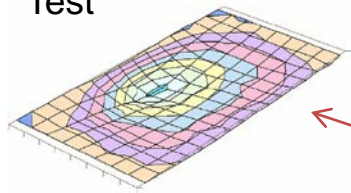


- SAE-2008-01-0781



- Vlahopoulos et al., Army Science 2010

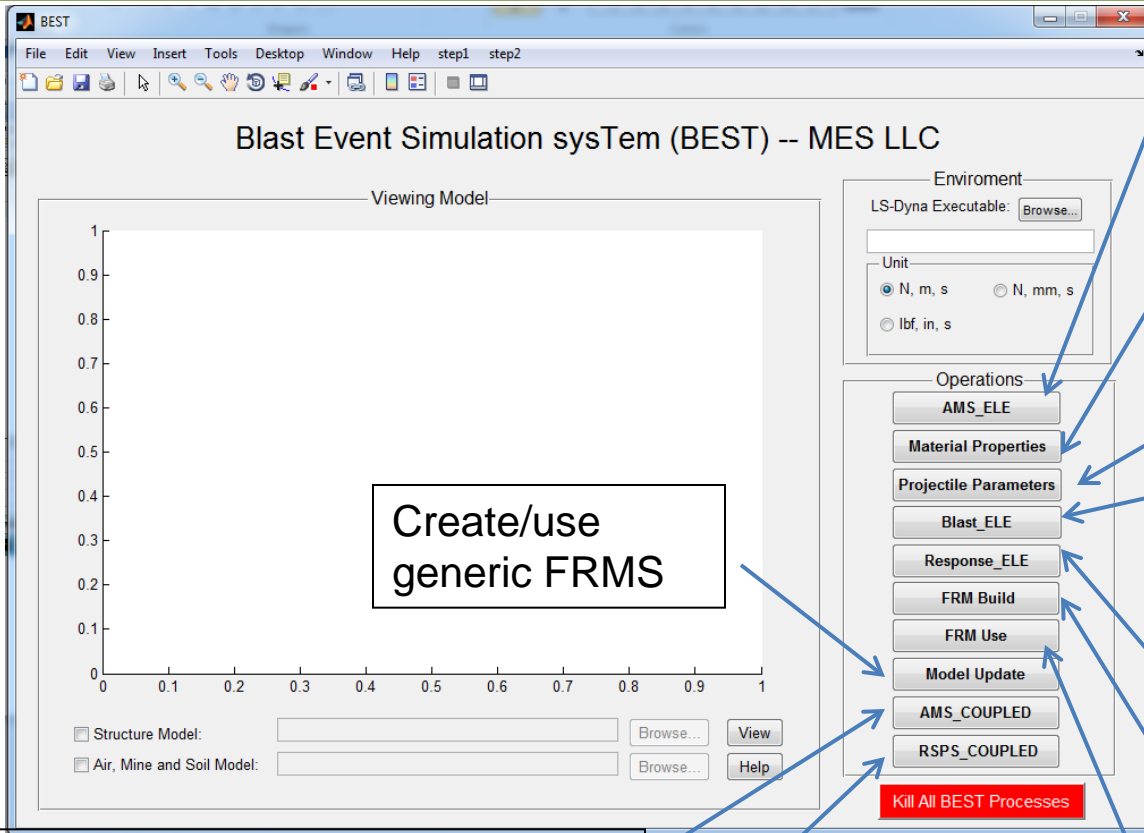
Test



BEST Structure

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Generate air/soil/explosive model for 2-stage analysis

Material definition for soil, air, explosive. Varies due to moisture content.

Creation of projectiles as part of the explosive threat

LS-Dyna Eulerian analysis for 2-stage analysis

LS-Dyna Lagrangian analysis for 2-stage analysis

Create fast running models for underbody blast studies

Use fast running models for underbody blast studies

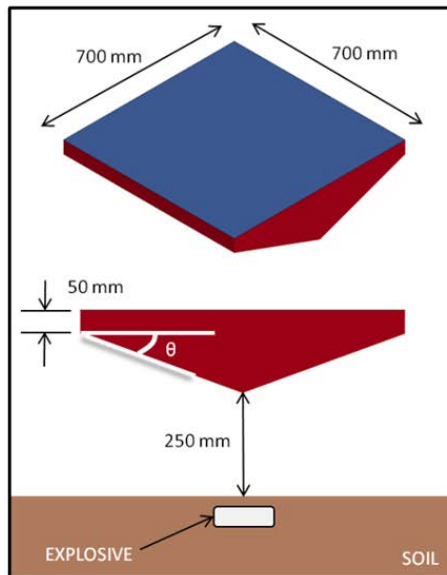
Create/use generic FRMS

Generate air/soil/explosive model for coupled analysis

LS-Dyna Lagrangian analysis for 2-stage analysis



- Emerging validation results for v-hull structure with varying geometry and charge size



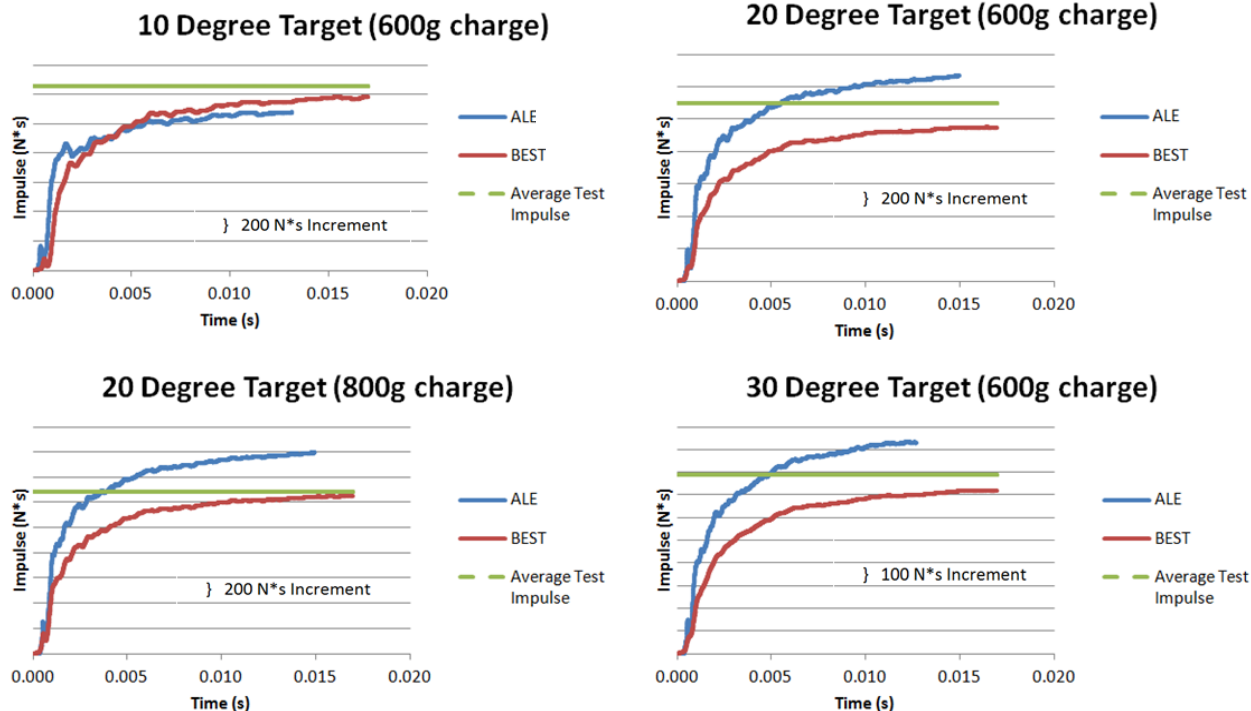
Test matrix:

Geometry (θ)	10 Degree	20 Degree	30 Degree	
Charge	600 g	600 g	800 g	600 g
Number of Tests	4	4	4	4
				Total Tests
				16





- Emerging correlation results with averaged experimental tests are at least as strong as fully-coupled ALE simulations

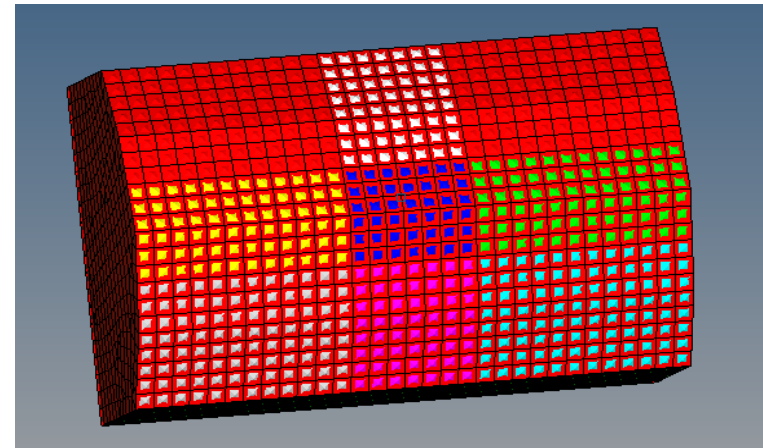
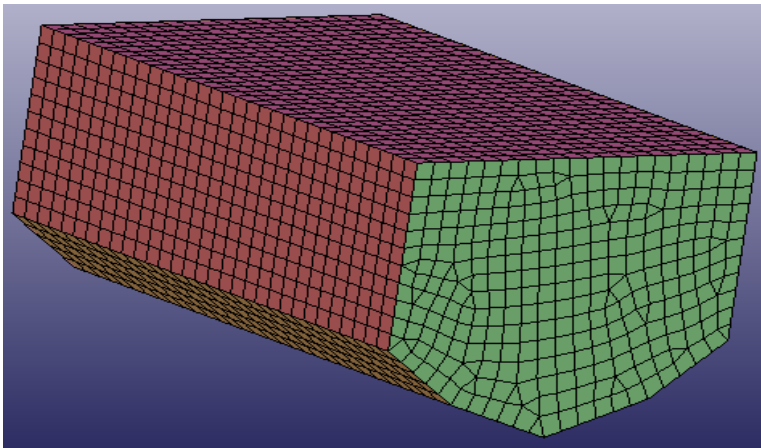
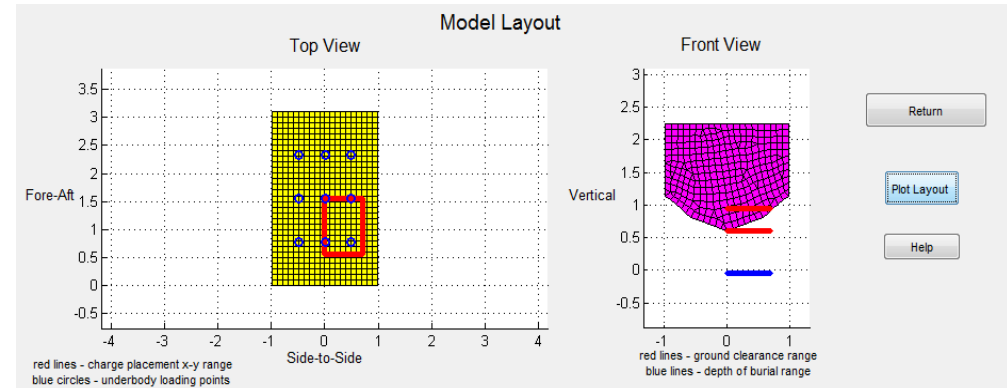


FRM Terminology

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- Input parameters
- Training points
- Loading points
- FRM applicable range



BEST FRM Build Interface

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Build training point
files and FRM

Specify parameter
ranges

View loading point
and FRM
configuration

The screenshot displays the FRMBUILD software interface, which is used for building training point files and FRM (Fragmentation Risk Model) configurations. The interface is divided into several sections:

- FRM Build Section:** Contains a "Load pre_FRM file" button with a file path "C:\Users\lmes\Des" and a "Browse" button. Below this, a note states: "* Optional - only if FRM model previously exists".
- Parameter Ranges (Step 1):** A table for specifying parameter ranges for charge placement and burial depth.
- Build Section (Steps 2-7):** Contains buttons for "AMS Parameters", "Blast", "Generate Training Point Input Files", "Underbody Loading Point Grid", "FRM Format" (set to "TRUCK"), and "Generate FRM".
- Model Layout Section:** Contains two plots: "Top View" and "Front View".

Parameter Ranges Table:

	Min	Max
Charge x coordinate range	-.5	.5
Charge y coordinate range	.5	2.65
Ground clearance range	0	.25
Charge weight range	6	6
Depth of Burial	0.1	0.2

Model Layout Section:

- Top View:** A 2D plot showing the charge placement x-y range (red lines) and underbody loading points (blue circles). The x-axis ranges from -2 to 2, and the y-axis ranges from 0 to 3.
- Front View:** A 3D plot showing the ground clearance range (red lines) and depth of burial range (blue lines). The x-axis ranges from -1 to 1, and the z-axis ranges from -0.5 to 2.

Legend:

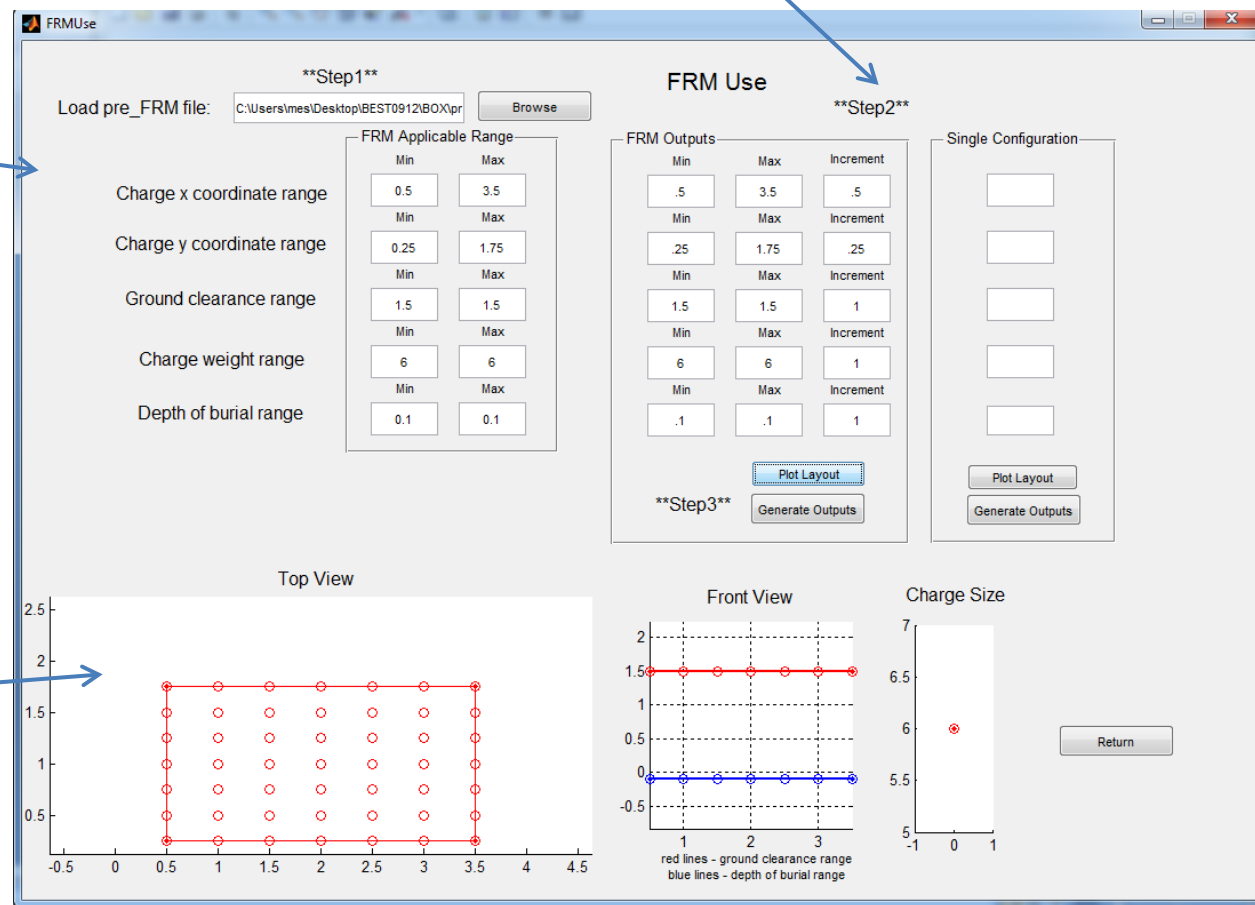
- red lines - charge placement x-y range
- blue circles - underbody loading points
- red lines - ground clearance range
- blue lines - depth of burial range

BEST FRM Use Interface

Desired mine/ vehicle configurations
for response study

Automatically
populated
applicability ranges

Visual representation
of FRM applicable
ranges



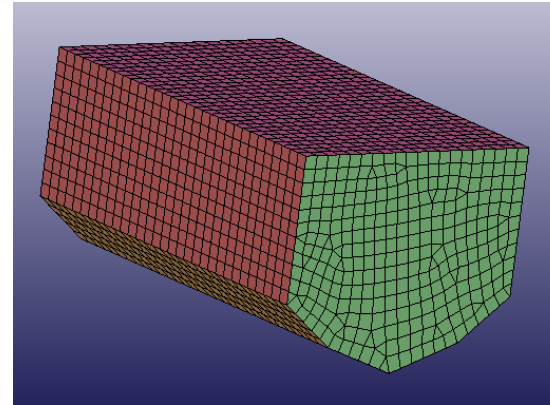
Case Study - FRM

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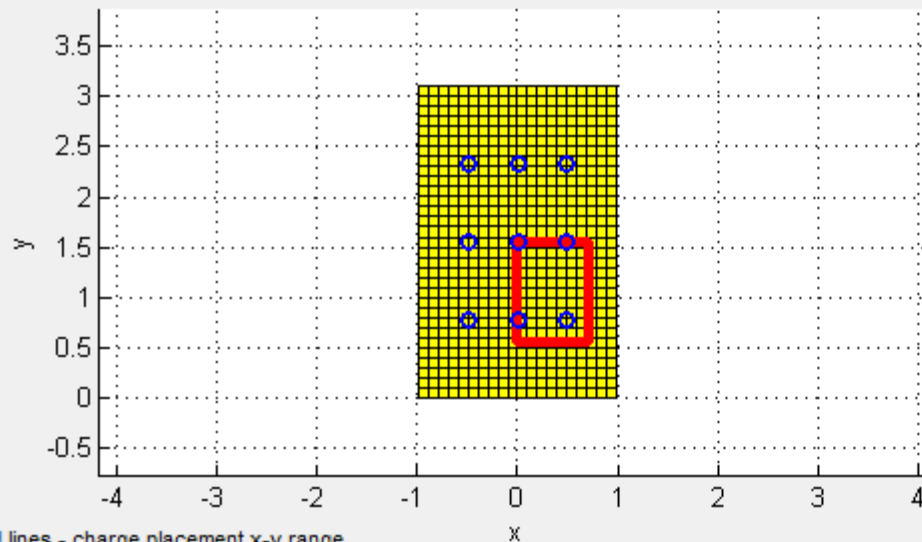
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- TARDEC V-hull
 - 20 Training Points
 - 9 Loading Points
 - 2 Evaluation Points

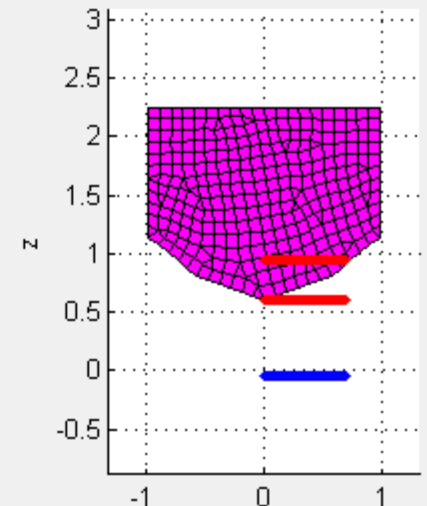


Top View



red lines - charge placement x-y range
blue circles - underbody loading points

Front View



red lines - ground clearance range
blue lines - depth of burial range

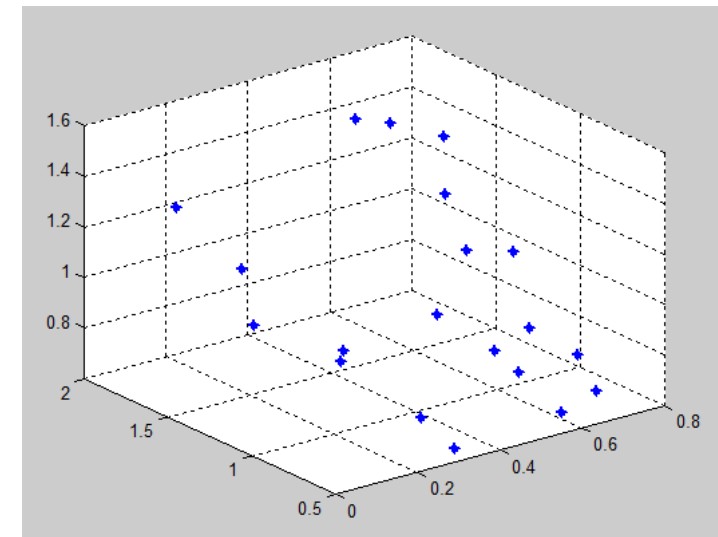
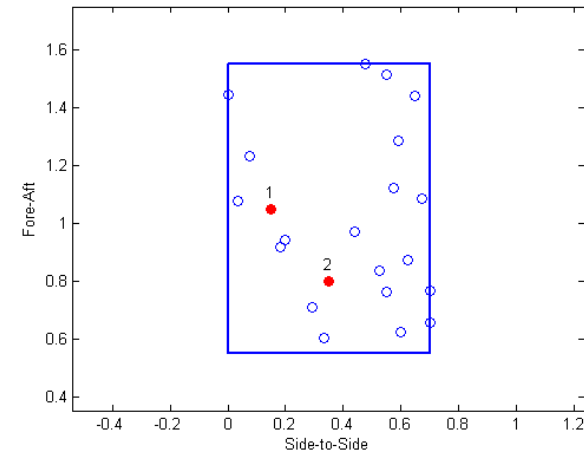
Training Points

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- Training point ranges:
 - x location range: 0.7m
 - y location range: 1 m
 - ground clearance range: 0.65 m
 - depth of burial: 0.0508 m
 - charge size: Stanag Level 2
- Vehicle Dimensions:
 - width: 1.978
 - length: 3.1025
 - height: 1.6499



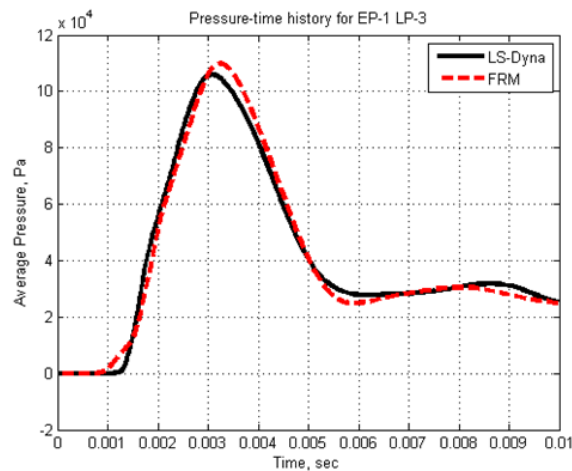
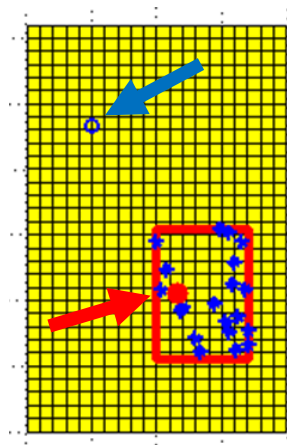
FRM Results

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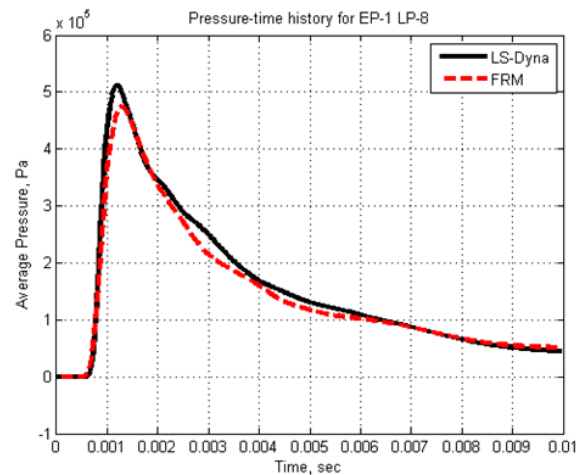
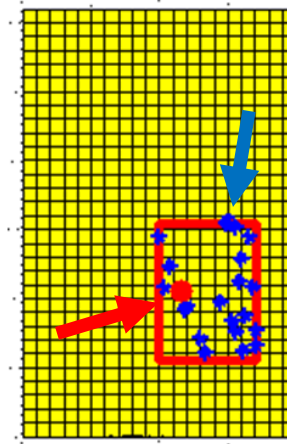
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- EP-1 LP-3:



- EP-1 LP-8:



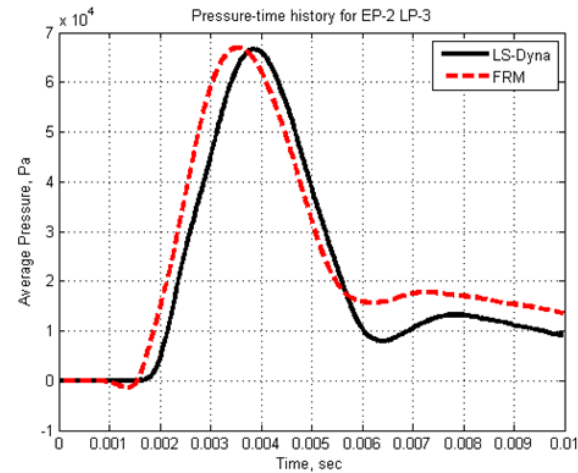
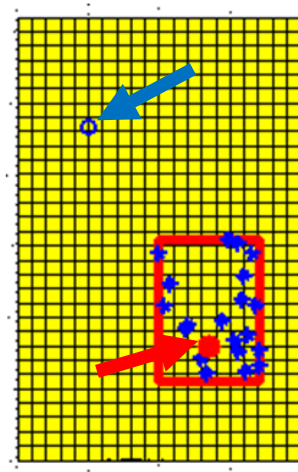
FRM Results

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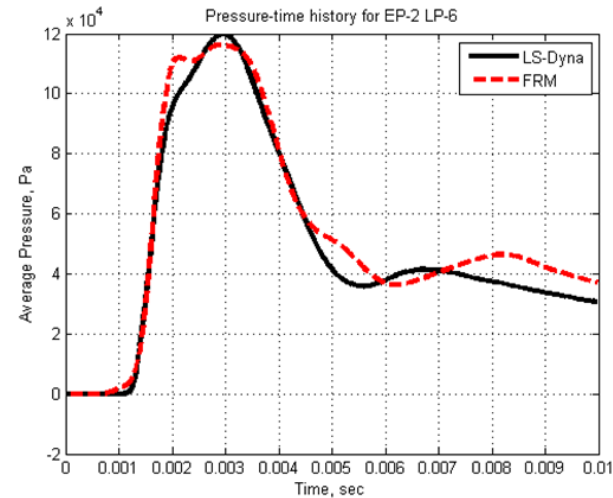
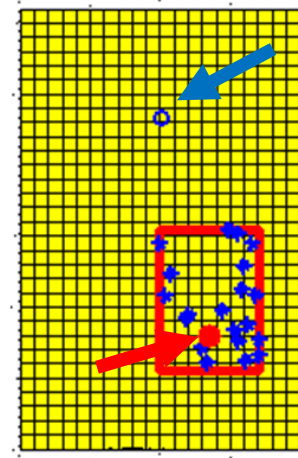
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- EP-2 LP-3



- EP-2 LP-6



Case Study - Metamodel



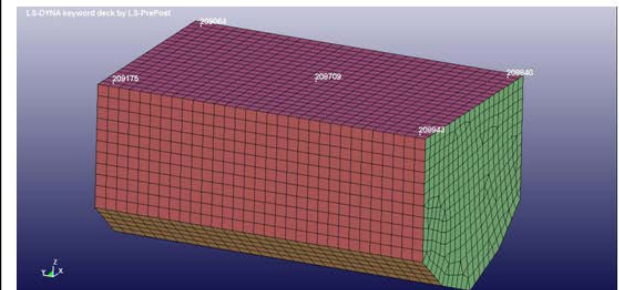
- FRMs can also be utilized to predict structural response
- Displacement of vehicle underbody tracked at all bottom nodes (630 total) to study **maximum displacement**
- Roof velocity tracked at 5 locations on roof to study **maximum average velocity**

Maximum Average Velocity \bar{V}_{Max} at One Surface of Hull: (Four Sides and Roof).

$$V_j(t_k) = \sqrt{V_{xj}^2(t_k) + V_{yj}^2(t_k) + V_{zj}^2(t_k)} \quad (\text{jth Node at time step } t_k)$$

$$\bar{V}(t_k) = \frac{\sqrt{\sum_{j=1}^N V_j^2(t_k)}}{N} \quad (N=5) \text{ at time step } t_k$$

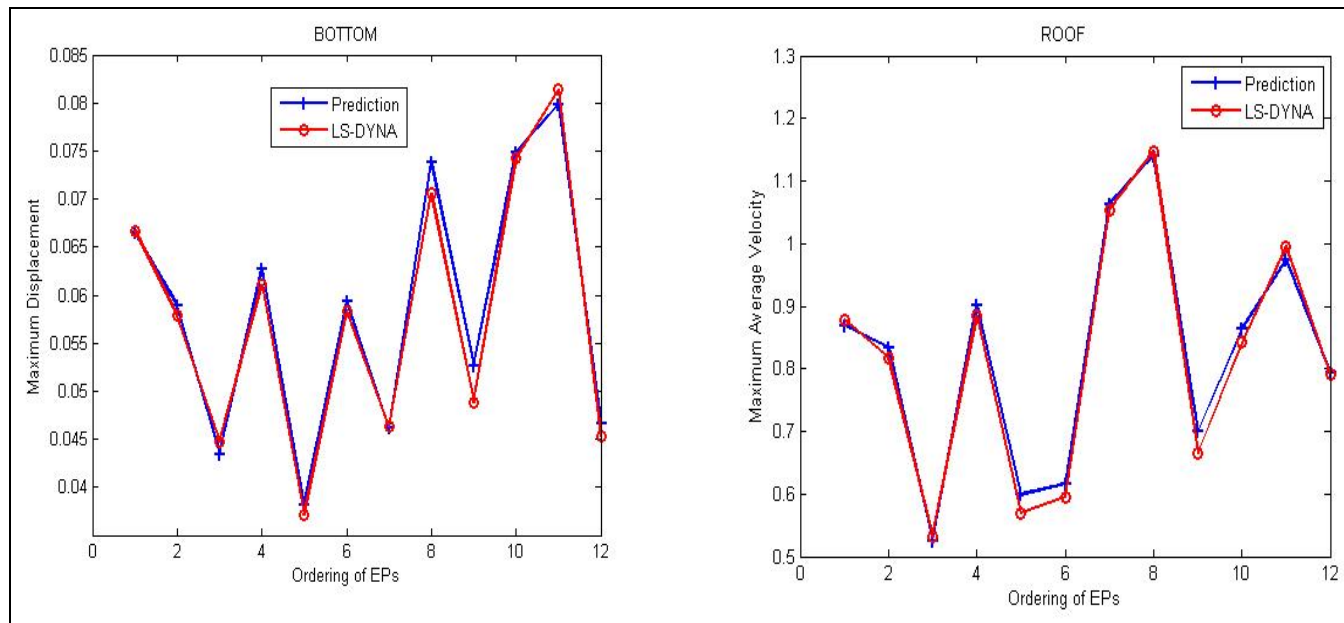
$$\bar{V}_{Max} = \text{Max}[\bar{V}(t_k)]$$



Metamodel Results



- Both the maximum displacement and the maximum average velocity results correlate well with LS-DYNA simulation over 12 evaluation points





Conclusions



- FRMs enable rapid evaluation of an entire matrix of vehicle/explosive configurations
- Both blast histories and structural responses can be modeled using FRMs
- The FRM capability has been incorporated in BEST to model any time-domain based physical event



- Two-step BEST approach justification:

